Perspectives in Science (2016) 8, 367—369

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Analysis of process parameters in surface grinding using single objective Taguchi and multi-objective grey relational grade☆

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Received 6 February 2016; accepted 12 April 2016
Available online 27 April 2016

KEYWORDS
Nanofluids;
MQL grinding;
Enhanced heat transfer;
Grey relational analysis

Summary Close tolerance and good surface finish are achieved by means of grinding process. This study was carried out for multi-objective optimization of MQL grinding process parameters. Water based Al_2O_3 and CuO nanofluids of various concentrations are used as lubricant for MQL system. Grinding experiments were carried out on instrumented surface grinding machine. For experimentation purpose Taguchi's method was used. Important process parameters that affect the G ratio and surface finish in MQL grinding are depth of cut, type of lubricant, feed rate, grinding wheel speed, coolant flow rate, and nanoparticle size. Grinding performance was calculated by the measurement G ratio and surface finish. For improvement of grinding process a multi-objective process parameter optimization is performed by use of Taguchi based grey relational analysis. To identify most significant factor of process analysis of variance (ANOVA) has been used.

Introduction

Close tolerances and good surface finish are obtained by the grinding process. Cutting fluids are used to improve lubrication, flushing away chips, reduce workpiece thermal damage, and for improvement of surface finish (El Baradie, 1996). In conventional flood surface grinding large amount of grinding fluid 5500 ml/min is poured in to grinding zone. Cost of recycling, environmental pollution, health hazard to machine operator are the negative impacts of conventional grinding process (Malkin and Guo, 2007). Grinding fluid reduction is obtained by means of minimum quantity lubrication (MQL) or dry grinding. In dry grinding thermal damage takes place on work surface. MQL is a best alternative to the dry grinding. In MQL, lubrication and cooling effects are ensured. Advantages of flood and dry grinding are integrated in MQL process. For MQL process grinding fluid flow rate is in the range of 20—100 ml/hour. The mixture of nanoparticles and water with compressed air is used as a cooling fluid. In MQL technology lubrication effect is provided by

☆ This article belongs to the special issue on Engineering and Material Sciences.
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http://dx.doi.org/10.1016/j.pisc.2016.04.077

Table 1 ANOVA for grey relational grade.

Source	DF	SS	MS	*F*-Value	*P*-Value	Contribution
Coolants	2	0.239	0.119	19.6	0.00	48.76
Concentration	2	0.012	0.006	1.04	0.38	2.56
Depth of cut	2	0.102	0.051	8.43	0.01	20.88
Feed rate	2	0.029	0.014	2.42	0.13	6.00
Coolant flow rate	2	0.004	0.002	0.36	0.70	0.89
Nanoparticle size	2	0.012	0.006	1.05	0.37	2.60
Grinding wheel speed	2	0.016	0.008	1.38	0.28	3.42
Error	12	0.072	0.006			
Total	26	0.490				

nanoparticles and compressed air ensures cooling of grinding zone. Wang evaluated that nanoparticles enhance the heat carrying capacity of base fluid (Wang et al., 2013). Silva et al. concluded that MQL technique improves wheel wear rate and reduces tangential cutting force in comparison with conventional cooling. Bin Shen et al. and Heisel et al. studied grinding of cast iron with different lubricating conditions and they found that there was remarkable positive improvement for grinding force, G ratio, and surface finish (Heisel et al., 1998). Cong Mao et al. reported that MQL grinding is more environmental friendly, economic, and nanoparticle works as a ball bearing around the workpiece which improves lubrication effect (Mao et al., 2012). Zhang Dongkun et al. had studied specific grinding energy for dry, flood, and MQL grinding conditions.

Many researchers had studied and reported positive results of MQL technology for grinding application. But, very less research is available for optimization of MQL grinding process. Grey relational analysis effectively optimizes the system parameters and inter-relationship of multiple performance characteristics (Tsao, 2007).

In this study, for optimization of MQL grinding process Grey-Taguchi's procedure is adopted. The controlled factors for grinding operation are depth of cut, type of lubricant, grinding wheel speed, coolant flow rate, nanoparticle concentration, and nanoparticle size. Grinding performance was evaluated by the calculation of G ratio and surface finish. Here we are optimizing the effect of controlled factors on grinding performance.

Experimentation and measurements

On an instrumented surface-grinding machine the grinding experiments were conducted. Lubricant was supplied by MQL fluid delivery system at variable coolant rate of flow (5, 10, and 15 ml/min). Abrasives of grinding wheel are of average size. The grinding wheel dimensions were 150 mm diameter and 14 mm width. Work material was prepared from EN8 flat plate. The dimension of workpiece material was 8 mm in width and 60 mm in length. Grinding wheel surface speed was set at (25, 30, and 35 m/s) and depth of cut at (5, 10, and 15 μm). The surface grinding operation was performed at the table speed of (2000, 2500, and 3000 mm/min) in unidirectional way. The dynamometer had recorded the workpiece tangential and normal force of grinding operation. Thermocouple embedded on a workpiece records temperature of grinding zone. Surface roughness of the ground surface was measured by the use of profilometer.

Table 1.

Design of experimentation with Taguchi method

Taguchi's high quality experimental design method is very effective for reduction of experimentation efforts, cost, and time. Design of experiments is done by specially constructed orthogonal array. Controlled factors are to be studied at three different levels. For this L_{27} orthogonal array was used. As per the design of the L_{27} orthogonal array 27 tests were conducted. For this research G ratio and surface finish were chosen as quality characteristics.

Experimental results

Signal to noise (S/N) ratio analysis

The deviation of quality characteristics from the desired value is indicated by S/N ratio. Higher S/N ratios are preferred for optimal level of process parameters. As per Fig. 1,

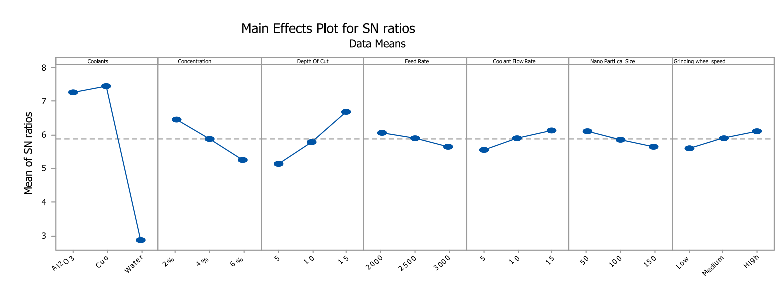

Figure 1 S/N ratios plot for Surface finish.

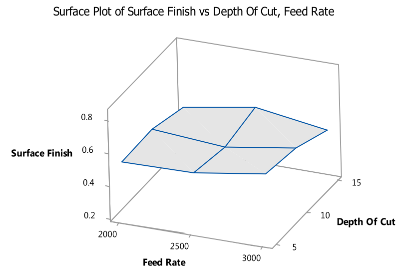

Figure 2 3D surface plot for effect of feed rate and depth of cut on surface finish.

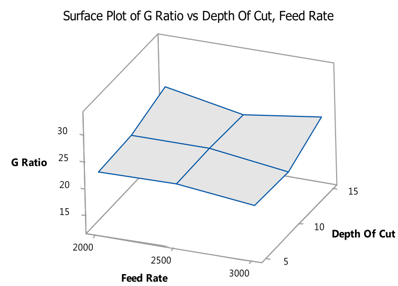

Figure 3 3D surface plot for effect feed rate and depth of cut on G Ratio.

optimal process parameters for good surface finish are coolant- CuO, concentration-2%, feed rate 2000 mm/min, coolant flow rate 15 ml/min, depth of cut-15 µm, nanoparticle size 50 nm, and grinding wheel speed 35 m/s. From the entire main effect plots we can analyse that type of coolant is the most important factor among the responses. This is due to the gradient slope is more for the figure.

Effect of grinding process parameters on responses

Three-dimensional surface graphs are used for the graphical analysis of the effect of grinding parameters on G ratio and surface finish. Three-dimensional surface plots for G ratio and surface finish are shown in Figs. 2 and 3. Surface finish of workpiece improves with increment in coolant flow rate and decreases with increase in feed rate (Fig. 2). G ratio improves with improvement in coolant flow rate and depth of cut (Fig. 3).

Multi-objective optimization by use of grey relational

Grey relational analysis determines the optimal combination of MQL grinding process parameters that simultaneously minimizes surface roughness and increases G ratio. It can be performed as-

Normalization of experimental data

In normalisation the experimental data is linearly normalized in the range of one to zero.

Evaluation of grey relational coefficient

This coefficient expresses the relation of actual and experimental outcomes.

Evaluation of grey relational grade

The average of grey relational coefficient is used for the calculation of grey relational grade (GRG).

Evaluation of grey relational order

Experimental order is done in accordance with value of GRG. As per the grade of experiment order is assigned. According to data the controlled parameters for experiment 10 had highest grey relational order. This shows that experiment 10 has optimal grinding factors setting for minimum surface roughness and maximum G ratio and they are as coolant CuO, concentration 2%, depth of cut 5 µm, coolant flow rate 5 ml/min, feed rate 2000 mm/min, nanoparticle size 100 nm, and grinding wheel speed 35 m/s.

Analysis of variance (ANOVA)

Percentage contribution of variables gives impact of that individual variable on total process. The most important controlled parameter variables affecting the GRG are coolants (48.76%) followed by depth of cut (20.88%), feed rate (6%). Coolant flow rate, nano particle size, and grinding wheel speed had less effect on GRG.

Conclusion

Grey Taguchi's multi-objective optimization technique was proposed to improve the MQL grinding process parameters for surface grinding of EN 8 material. From experimental investigation and grey Taguchi's multi-objective optimization technique following conclusions are made.

- The best optimized process variable combination for maximum surface finish on the basis of multi-objective grey relational analysis are coolant CuO, concentration 2%, depth of cut 5 µm, coolant flow rate 5 ml/min, nanoparticle size 100 nm, feed rate 2000 mm/min, and grinding wheel speed 35 m/s.
- As per ANOVA results for GRG, type of coolant is having major contribution in GRG figure.
- Production quality and work efficiency can be increased by properly adjusting process parameters.

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